SOME INITIAL SEDIMENT-ASSOCIATED TRACE ELEMENT RESULTS FROM THE CITY OF ATLANTA WATER-QUALITY MONITORING NETWORK

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Abstract. In cooperation with the City of Atlanta, Georgia, the U.S. Geological Survey has implemented a water-quantity and -quality monitoring network that measures a variety of biological and chemical constituents in water and suspended sediment. The network consists of 20 long-term monitoring sites and is intended to assess water-quality trends in response to planned infrastructural improvements. Initial results from the network indicate that nonpoint-source contributions may be more significant than point-source contributions for selected sediment associated trace elements and nutrients. There also are indications of short-term discontinuous point-source contributions of these same constituents during baseflow.

INTRODUCTION

Population growth and urbanization impact local landscapes and the quantity and quality of water in nearby rivers and streams, as well as on downstream receiving waters (Ellis, 1999). Typical impacts may include: (1) disruption of the normal hydrologic cycle through increases in the extent of impervious surfaces that limit infiltration and raise the velocity and volume of surface runoff; (2) increased chemical (organic, inorganic, and nutrient) loads to local and downstream receiving waters due to specific industrial sources, nonpoint-source runoff, leaking sewer systems, and sewer overflows; (3) direct or indirect soil contamination from industrial sources, power-generating facilities, and landfills; and (4) reduction in the quantity and quality of aquatic habitats (Driver and Troutman, 1989; Ellis, 1999; Rose and Peters, 2001).

Atlanta, Georgia, has been and continues to be one of the most rapidly-growing urban areas in the United States. Between the early 1970s and 2000, the population of Metropolitan Atlanta increased by about 125 percent (%); contemporaneously; depending on the definition, urbanization has increased between 115 and 210% (Peters and Kandell; 1999; Atlanta Regional Commission, 2004; E.A. Kramer, University of Georgia, personal commun., 2004). As a result, the City of Atlanta's (COA) storm and sanitary sewers have been unable to meet current demands. About 15% of the current COA sewer system is combined (stormwater and sanitary waste in the same pipe). During dry periods, all sewer flows are discharged to wastewater treatment plants; whereas under wet conditions, some of these flows are sent to combined treatment facilities (Fig. 1). During major storms, the combined system can be overtaxed, and untreated sanitary waste and stormwater may be directly discharged to local streams. On average, there are more than 300 combined sewer overflows (CSOs) per year from the six existing CSO facilities (Fig. 1) (Clean Water Atlanta, 2004).

During 1995, a group of environmental organizations filed suit against the COA for violations of the Clean Water Act relative to CSO impacts on downstream water quality, subsequent lawsuits were initiated by the State and Federal governments concerning sanitary sewer spills and stormwater. During 1998, the COA entered into a consent decrees, with all the litigants, to reduce the incidence of CSOs and to reduce sanitary and stormwater discharges to permitted limits (U.S. District Court, 1998). During 2001, the COA asked the U.S. Geological Survey (USGS) to design a water-quality monitoring network that would fulfill the requirements of the consent decree, as well as provide an evaluation of the effectiveness of the infrastructural improvements. The monitoring program provides real-time measurements of water quantity (discharge) as well as quality (e.g., pH, conductance, and turbidity), combined with manual and automated sampling and subsequent chemical/biological analyses. Sampling media include filtered water, suspended sediment, and bed sediment; whereas measured constituents include major ions, trace elements, nutrients, bacteria, and sewage tracers. Some of the initial sediment-associated trace element and nutrient results are described herein.

SAMPLING DESIGN AND METHODS

The COA water-quality monitoring network initially consisted of 20 long-term sites (Fig. 1). Ten of the sites are "fully instrumented" to provide real-time measurements of water temperature, pH, specific conductance, dissolved oxygen, turbidity (intended as a surrogate for suspended sediment concentration [SSC]), water level (gage height, intended as a surrogate for discharge), and rainfall; these parameters are measured at 15-minute intervals.

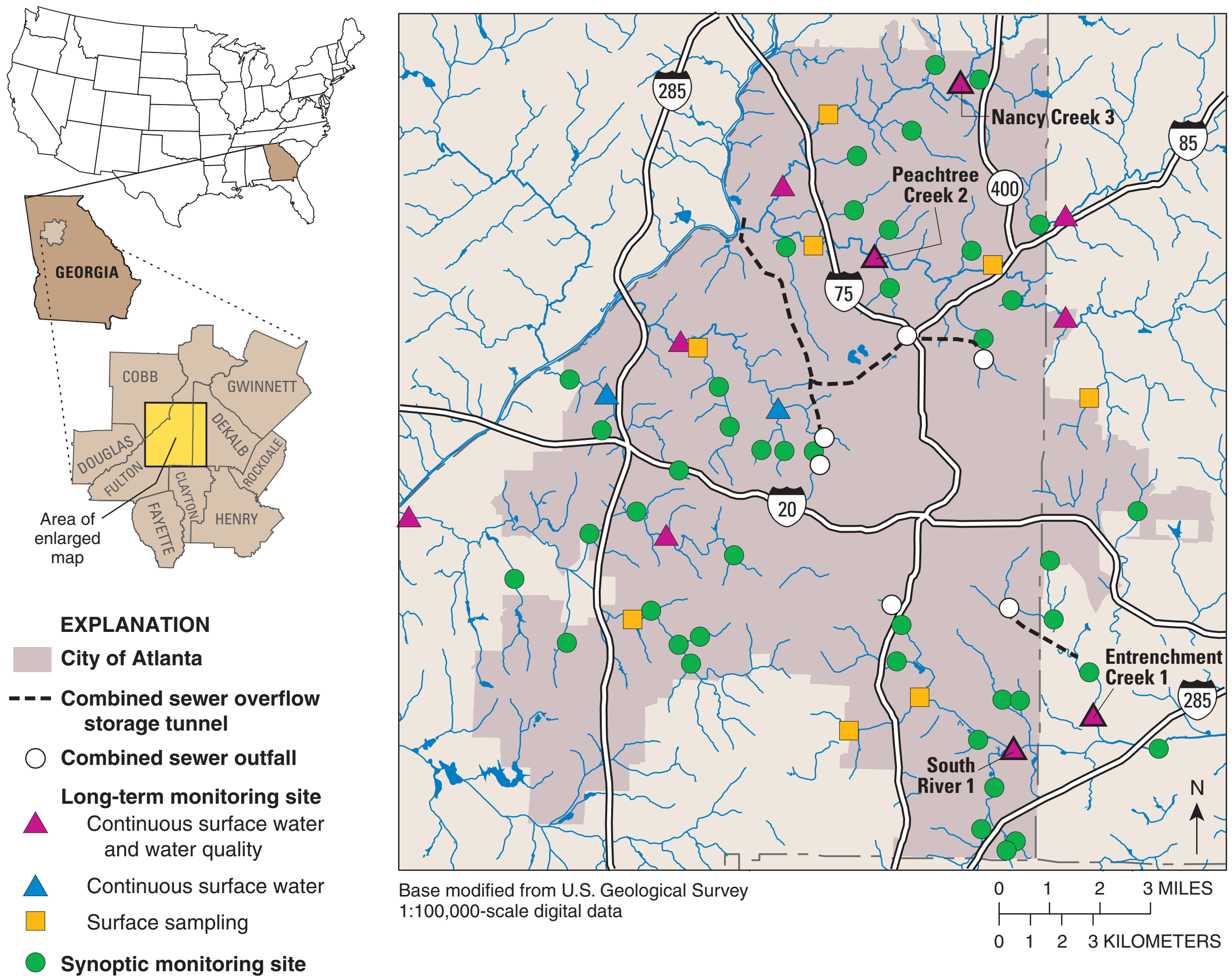

Figure 1. The City of Atlanta and the location and types of sampling sites in the long-term water-quality monitoring network (modified from Joiner, 2003).

Data are transmitted hourly to the local USGS Georgia District Office and are uploaded to a publicly accessible Web site soon after (*http://ga.water.usgs.gov*). All fully instrumented sites are equipped with programmable automatic samplers to capture stormflows. These samplers are particularly important because substantial suspended sediment, sediment-associated, and dissolved chemical constituent transport occurs during storms (e.g., Horowitz, 1995; Peters and Kandell, 1999; Rose and Peters, 2001). Two of the remaining long-term monitoring sites only are instrumented to measure water level and rainfall. The remaining eight sites only are used to assess water quality; however, instantaneous discharge is measured during sampling.

Real-time data collection is complemented with a manual sampling program that has two components. The first, completed during the first year of the program (2003), is a pair of intensive (scheduled for 7- to 10-day periods) synoptic surveys; one conducted under high-flow and one conducted under baseflow conditions. The synoptic surveys covered 43 sites beyond those in the long-term monitoring network (Fig. 1). The second component of the manual program consists of the collection of scheduled samples and nonconvective storm samples. Manual sampling follows standard USGS depth- and width-integrated isokinetic procedures to ensure the collection of cross-sectionally representative samples (e.g., Edwards and Glysson, 1999). Each site in the network is sampled 12 times per year; however, due to the linkage between discharge and water quality, scheduled sampling is not calendar- but hydrologically-based (e.g., Horowitz, 1995). The intent is to collect samples covering from at least 80 to 85% of the typical range of annual discharges.

INITIAL RESULTS AND DISCUSSION

Synoptic Surveys

The high- and low-flow synoptic surveys were completed during 2003. Generally, the mean/median concentrations for the majority of the sediment-associated constituents (trace elements and nutrients) were markedly higher in the high flow than in the low-flow samples (Fig. 2). This implies that nonpoint sources may contribute more than point sources, at least for sediment-associated constituents.

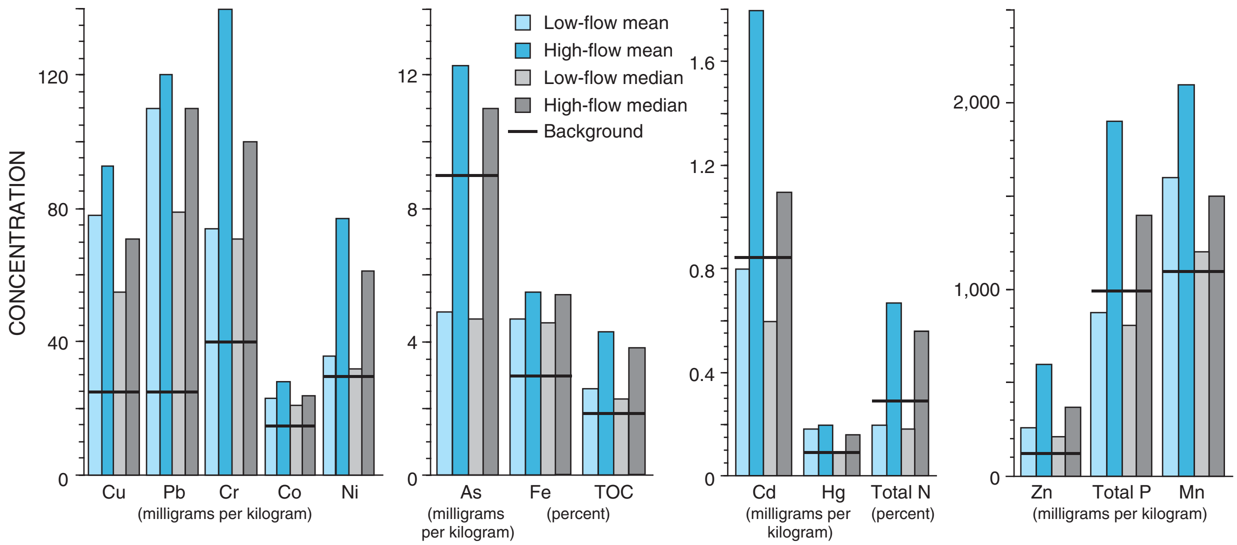

Figure 2. Selected mean/median sediment-associated chemical concentrations for the high- and low-flow synoptic surveys. The solid horizontal bars demark background chemical levels (e.g., Horowitz, 1995)
[Cu, copper; Pb, lead; Cr, chromium; Co, cobalt; Ni, nickel; As, arsenic; Fe, iron; TOC, total organic carbon; Cd, cadmium; Hg, mercury; total N, total nitrogen; Zn, zinc; total P, total phosphorus; Mn, manganese]

Because the COA's planned infrastructural improvements are intended to deal with CSOs (point sources), and the synoptics indicate the importance of nonpoint-source contributions, the planned improvements may not provide as positive a downstream effect on some water-quality parameters as originally assumed. The concentrations of copper, lead, zinc, chromium, nickel, cobalt, mercury, iron, manganese, and total organic carbon exceeded typical background levels (e.g., Horowitz, 1995) during both surveys; whereas the concentrations of arsenic, cadmium, total nitrogen, and total phosphorus only exceeded background levels during the high-flow survey. Based on the synoptic surveys (elevated suspended sediment and chemical concentrations), an additional sampling site, Woodall Creek at DeFoors Ferry Road, was added as a long-term monitoring site.

Baseflow Sampling and Analyses

During the initial part of the COA monitoring program, a substantial number of baseflow samples were collected at the 20 long-term sites. On a site-specific basis, under baseflow conditions, many sediment-associated trace element and nutrient concentrations display little variation. On the other hand, a number of sites/constituents do display markedly elevated levels, independent of suspended sediment concentration (Fig. 3). This may indicate significant but discontinuous short-term, point-source discharges. The only way to quantify these contributions to the annual chemical fluxes at each site is to maintain a continuous sampling and chemical analysis program using automatic samplers to generate composites. As more monitoring data become available, particularly stormflow contributions to annual fluxes, a change in approach involving the collection and chemical analyses of continuous composites may be considered.

Stormflow Sampling and Subsequent Chemical Analyses

During the first 18 months of the program, several storms were sampled with the automatic equipment, and a limited number of concurrent and automated samples were collected. As a result, several stormflow and storm-related water-quality patterns have begun to emerge. Some of these patterns have been observed during previous monitoring programs (e.g., Horowitz, 1995; Christensen, 2001). There are preliminary indications at sites where sufficient data have been generated that useful (predictive) interrelations may exist among SSC, discharge, and turbidity (Fig. 4). Somewhat surprisingly, these initial results indicate that there may be little difference between the concentrations (suspended sediment and sediment-associated constituents) obtained from the material collected with the automatic samplers and that collected manually. This may indicate that during high flows, there is sufficient energy, and/or the cross-sections are sufficiently narrow, to produce homogeneous suspended sediment distributions. If this proves to be the case, then data generated from the point measurements/samplers (data sondes and/or automatic samplers) may not require any correction for cross-sectional inhomogeneities. This conclusion obviously is preliminary and requires confirmation.

The pattern of temporal change in SSC and associated chemical constituents during a storm has been reported before (e.g., Horowitz, 1991; 1995). At the beginning of an event, SSC concentrations tend to be relatively low, size

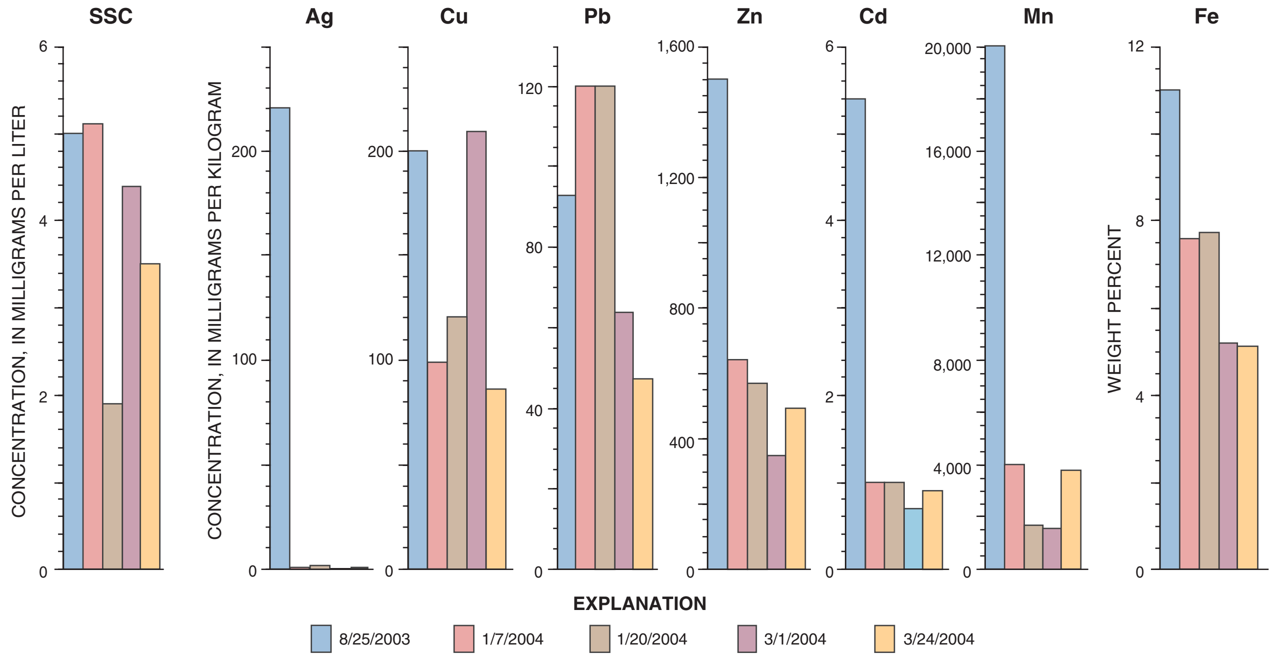

Figure 3. Suspended sediment concentration and selected sediment-associated chemical concentrations for baseflow samples collected on different dates (horizontal axis) collected at a single Peachtree Creek monitoring site. Bars having the same fill pattern identify concentrations from individual samples, collected on the same date.
[SSC, suspended sediment concentration; Ag, silver; Cu, copper; Pb, lead; Zn, zinc; Cd, cadmium; Mn, manganese; Fe, iron]

distributions tend to be dominated by finer-grained material (≤63 micrometers [µm]), and sediment-associated chemical concentrations (e.g., milligrams per kilogram [mg/kg]) tend to be relatively high. As the storm progresses, SSC increases, grain-size distributions become coarser (≥63-µm increases), and, as a result, sediment-associated chemical concentrations decline. Conversely, for the same time period, due to increasing discharge, the mass of SSC and sediment-associated constituents (e.g., micrograms per liter [µg/L]), and hence their fluxes, increase. This pattern also has been observed during sampled/measured COA storm events (Fig. 5).

One of the major issues associated with the use of automatic samplers is how/when to "trigger" them. This is particularly true in urban hydrology studies due to the importance of collecting the first "flush" of material after a period of antecedent dry conditions (e.g., Larsen et al., 1999). If the only purpose of the sampling program is to evaluate dissolved constituents, the normal procedure is to trigger the sampler based on stage (discharge) change. However, this approach may be inappropriate when dealing with suspended sediment because of hysteresis (e.g., when the SSC peak either leads and/or lags behind the discharge peak). Because the interrelation between discharge and SSC is site specific, each fully instrumented site has to be evaluated individually (Walling and Webb, 1981; 1988; Horowitz, 1995). At least some of the COA monitoring sites clearly display leading hysteresis patterns (e.g., Nancy Creek 1 and Intrenchment Creek; Fig. 6) whereas others do not (e.g., South River 1; Fig. 6). Note that at least for some of the COA monitoring sites, the hysteresis issue may be exacerbated because the delay between the SSC peak and the discharge peak may not be constant, particularly when the time period between storm events is short (Fig. 6). The hysteretic changes detected at Intrenchment and Nancy Creeks may well reflect the loss of easily erodable material on and/or near the banks/floodplains of these creeks and/or at least the temporary removal of sediment stored in the streambed.

SUMMARY

1. A long-term water-quality monitoring network, incorporating 20 sites and measuring a variety of chemical and biological constituents, has been established for the City of Atlanta.
2. The results from a high- and low-flow synoptic survey indicate that contributions to sediment-associated trace elements and nutrients from nonpoint sources appear to be greater than those from point sources.
3. Baseflow sampling and subsequent chemical analyses indicate the possible presence of significant short-term discontinuous point-source discharges.
4. During the course of a storm, the concentrations of sediment-associated chemical constituents tend to decline; however their masses, and hence their fluxes tend to increase.
5. Initial data indicate useful but site-specific interrelations between discharge, SSC, and turbidity that ultimately should permit the prediction of SSC in the absence of actual samples.

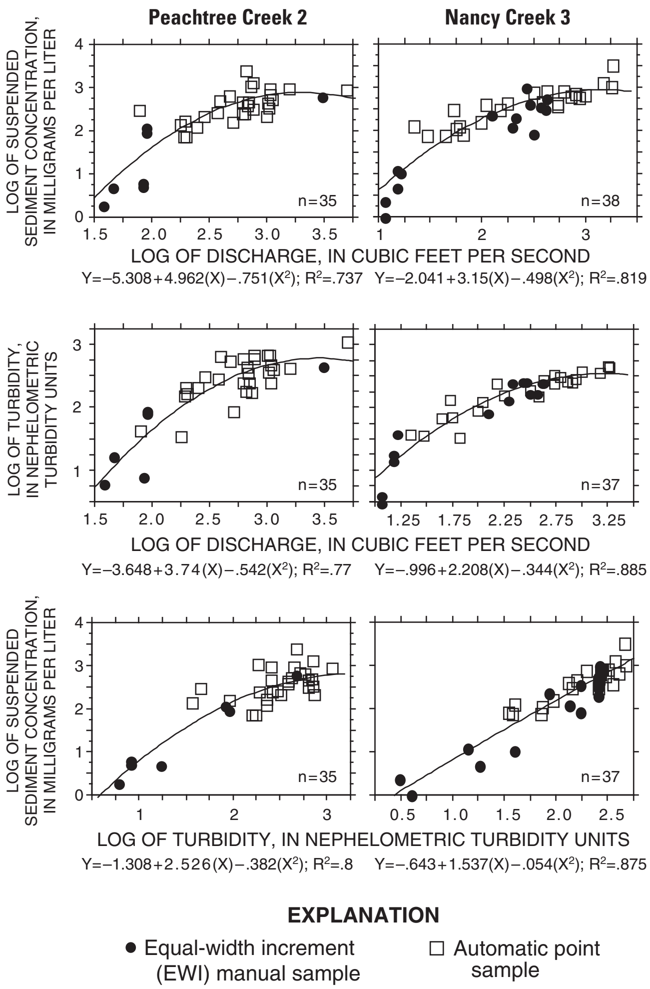

Figure 4. Regression curves displaying the preliminary interrelations between suspended sediment concentration, discharge, and turbidity for both manual and automatic samples collected at the Peachtree Creek 2 and Nancy Creek 3 monitoring sites.

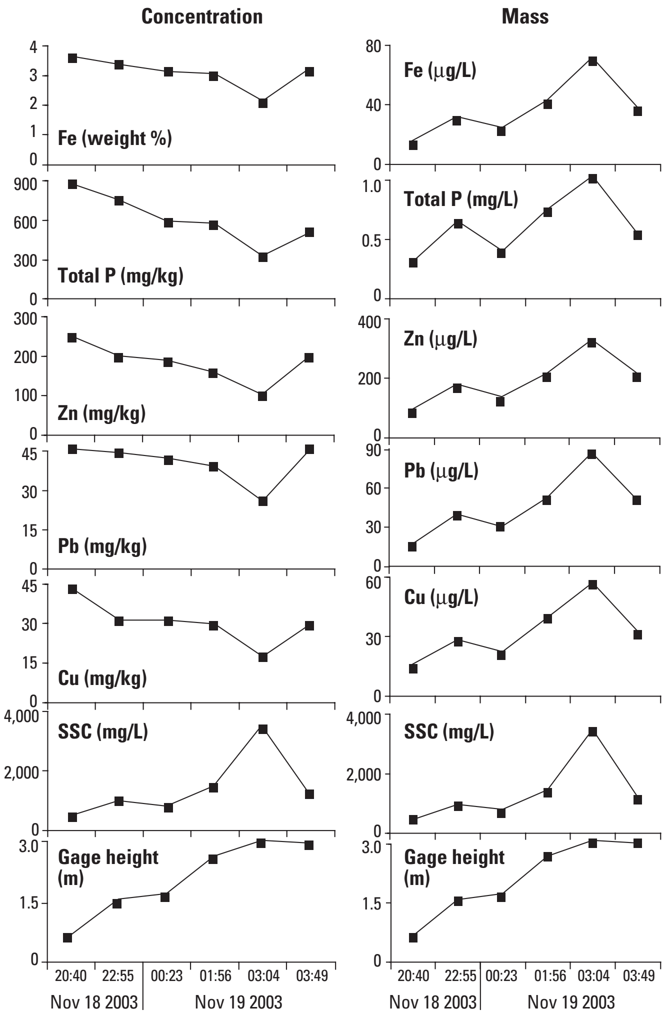

Figure 5. Changes in selected suspended sediment-associated chemical concentrations and masses, as well as suspended sediment concentration and gage height during a single storm at the Nancy Creek 3 monitoring site.
[Fe, iron; total P, total phosphorus; Zn, zinc; Pb, lead; Cu, copper; SSC, suspended sediment concentration; %, percent; mg/kg, milligrams per kilogram; mg/L, milligrams per liter; µg/L, micrograms per liter; m, meter]

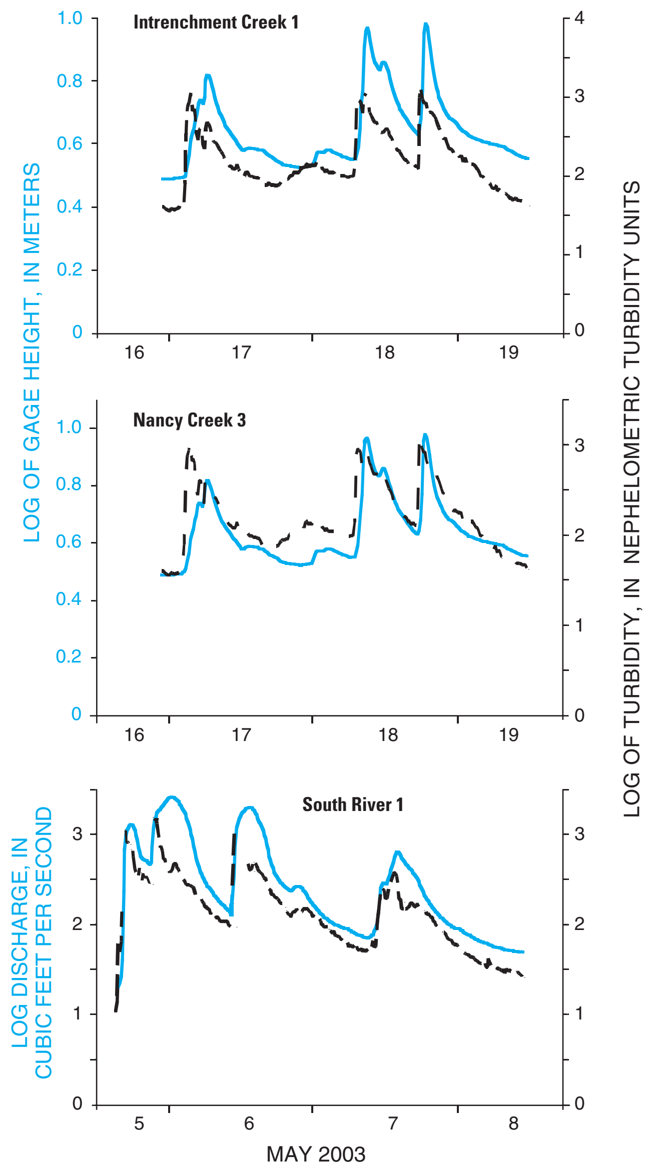

Figure 6. Interrelations between gage height or discharge and turbidity (all log-transformed) during a series of sequential storms at three sites in the City of Atlanta long-term water-quality monitoring network.

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